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Optimum Design of DG-Based Distribution System Considering Power Quality and Reliability Indices Using PSO

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Abstract: The new idea of this paper is optimization of DG units based on combination of power quality and reliability improvement in system. In this research the multi objective optimal placement of distribution generation (DGs) in distribution system is addressed .the basic of objective function considered in this paper relies on power quality and reliability improvement. The implemented technique relies on Particle Swarm Optimization (PSO) and weight coefficient method (WCM). Simulation results on 12-bus distribution test system are presented to show the effectiveness of the proposed approach. The power quality indices that considered in objective function are power loss reduction, voltage stability improvement. The reliability index that is studied in this paper combination of several reliability indices using and weight coefficient and this indices contain average energy not supplied, customers' average interruption duration index and system average interruption duration index.

Key words: Distributed generation · Particle swarm optimization · Voltage stability · Short circuit level · Reliability

INTRODUCTION

Utilities are continuously planning the expansion of their existing electrical networks in order to face the load growth and to properly supply their consumers. Distribution system provides a final link between the high voltage transmission system and the consumer. Electricity networks are in the era of major transition from stable passive distribution networks with unidirectional electricity transportation to active distribution networks with bidirectional electricity transportation. Distribution networks without any DG units are passive since the electrical power is supplied by the national grid system to the customers embedded in the distribution networks. It becomes active when DG units are added to the distribution system leading to bidirectional power flows in the networks. In an active distribution network the amount of energy lost in transmitting electricity is less as compared to the passive distribution network, because the electricity is generated very near the load centre, perhaps even in the same building. DG-based distribution systems have several advantages like reduced line losses, voltage profile improvement, reduced emission of pollutants, increased overall efficiency, improved power quality and reliability and relieved T&D congestion. Hence, utilities and distribution companies need tools for proper planning and operation of DG-based distribution systems. In [1] optimum allocation of distributed generations based on evolutionary programming for loss reduction and voltage profile correction is considered.

In [2] application of Tabu search for optimal placement and sizing of distributed generation for loss reduction is studied.

In another study, the DG placement with considering reliability improvement and power loss reduction with GA method is analyzed in [3].

Optimal planning of distributed generation for improved voltage stability and loss reduction is investigated by [4].

In [5] the power quality indices have been considered in optimal location of distributed generation. It has analyzed the optimal placement and sizing of DG for loss reduction, voltage profile improvement and voltage sag mitigation.

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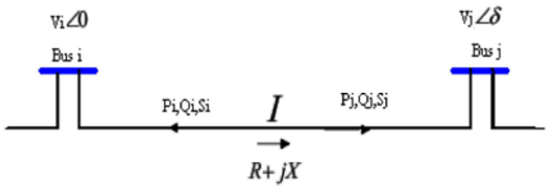

Fig. 1: 2-bus model representation

Of course, some papers have considered the economical aspects of optimization DGs on distribution system, for intense Optimal distributed generation planning considering reliability; cost of energy and power loss is investigated by [6].in other researches the optimization of DGs with considering protective device is presented. In [7] the multi-objective function includes a short circuit level parameter to represent the protective device requirements. Optimal placement of multi DG units including different load models using GA has investigated by this author. In [8-11] optimal DG placement in distribution systems using cost/worth analysis is investigated.

Modeling

Power Quality Improvement Indices

Voltage Stability Index (VSI): Accurate voltage stability contingency analysis could be accomplished by performing active load power-voltage magnitude curve study. Some other methods introducing different stability indices have also been introduced and compared in [12]. A line stability index LQP is proposed in [13]. The voltage stability index is derived from a 2 bus system as shown in Figure 1.

The current flow from sending bus to receiving bus can be computed as:

$$I = \frac{V_i\angle 0 - V_j\angle\delta}{R + jX} \tag{1}$$

where, R is the line resistance and X is the line reactance. The received complex power at receiving bus:

$$S_j = V_j \times I_j = P_j + jQ_j \tag{2}$$

In above equation we have:

$$\begin{cases} P = \left[\frac{R}{R^2+X^2}(V_i\cos\delta - V_j) - \frac{X}{R^2+X^2}(V_1\sin\delta)\right]V_j & (3) \\ Q = \left[\frac{X}{R^2+X^2}(V_i\cos\delta - V_j) - \frac{R}{R^2+X^2}(V_1\sin\delta)\right]V_j & (4) \end{cases}$$

If the line resistance is very small compared to the reactance we have:

$$\begin{cases} \sin\delta = \frac{XP_j}{V_iV_j} \\ \cos\delta = \frac{XQ_j + V_j^2}{V_iV_j} \end{cases} \tag{5}$$

Then:

$$(\frac{XP_j}{V_iV_j})^2 + (\frac{XQ_j + V_j^2}{V_iV_j})^2 = \\ = \sin^2\delta + \cos^2\delta = 1 \tag{6}$$

So

$$V_j^4 + (2XQ_j - V_i)V_j^2 + (X^2Q_j^2 + X^2P_j^2) = 0 \tag{7}$$

Consider this equation, to be equaled equation of V_j^2, for V_j^2 in order to have a real solution the follow expression must be satisfied:

$$(2XQ_j - V_i)^2 - 4(X^2Q_j^2 + X^2P_j^2) \geq 0 \tag{8}$$

So

$$Q_j \leq \frac{V_i^2}{4X} - \frac{P_j^2 X}{V_j^2} \tag{9}$$

Since the line is lossless, then $P_i = -P_j$, so we have:

$$4\left(\frac{X}{V_i^2}\right)\left(-\frac{X}{V_i^2}P_j^2 + Q_j\right) \leq 1 \tag{10}$$

The line stability index is therefore defined for line between bus I and bus j as:

$$VSI_{ij} = 4\left(\frac{X}{V_i^2}\right)\left(-\frac{X}{V_i^2}P_j^2 + Q_j\right) \tag{11}$$

When there is no load at bus j, the VSI_{ij} is 0, as the load in the system increases, the VSI_{ij} value increases from 0 to 1.the VSI_{ij} value must be smaller than 1 for the system to be stable. The higher VSI_{ij} value is, the closer the system is working near its stability margin. The system stability factor SSF in a contingency is defined as the biggest VSI_{ij} for all transmission lines. In case the system becomes unstable or collapse

Newton-Raphson's method for power flow analysis will not converge, therefore the system stability factor cannot be calculated correctly by performing power flow analysis. In this case, the SSF is assigned to be 1.

Power Loss Reduction: DG sources are normally placed close to load centers and are added mostly at the distribution level. They are relatively small in size (relative to the power capacity of the system in which they are placed) and modular in structure [13-15]. A common strategy for sizing and placement of DG is either to minimize system power loss or system energy loss of the power systems. The voltage at each bus is in the acceptable range and the line flows are within the limits. These limits are important so that integration of DG into the system does not increase the cost for voltage control or replacement of existing lines. The formulation to determining the optimal size and location of DG in a system is as follows:

Loss Reduction Factor Index per node is defined as the ratio of percentage reduction in loss from base case when a DG having size DGS KW is installed at bus i, to the DG size at that bus. Power Loss Reduction Index (PLRI) is expressed as:

$$PLRI = \frac{Ploss_{Base} - Ploss_{DGi}}{Ploss_{Base}} \quad (12)$$

where

After the iterative solution of bus voltages, line flows and line losses can be calculated. The complex powers Sij from bus i to j and Sji from bus j to i are:

$$\begin{aligned} Sij &= V_i I^*_{ij} \\ Sji &= V_j I^*_{ji} \end{aligned} \quad (13)$$

The power loss in line i-j is the algebraic sum of the power flows determined from the above equations.

$$Ploss = \sum_{i=1}^{N\_bus} \sum_{j=1}^{N\_bus} \operatorname{Re}\{S_{ji} + S_{ij}\} \quad (14)$$

Reliability Improvement: In order to guaranty the reliability of system, the paper calculates the three indices as illustrated follows:

SAIDI: System Average Interruption Duration Index:

It is commonly referred to as customer minutes of interruption or customer hours and is designed to provide information as to the average time the customers are interrupted.

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \quad (15)$$

Here Ui is interruption duration at i^{th} load point and Ni is the number of customer at i^{th} load point,

CAIDI: Customers Average Interruption Duration Index: It is the average time needed to restore service to the average customer per sustained interruption.

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (16)$$

Here λ_i is the annual failure rate at i^{th} feeder.

AENS: Average Energy Not Supplied:

It is defined as the ratio of the total energy not supplied to the total number of the customers as follows:

$$AENS = \frac{\sum L_a(i) u_i}{\sum N_i} \quad (17)$$

where

ENS_T : The total average energy not supplied when the fault happened in sequence in all the sections in the case of without DG.

ENS_i : The total average energy not supplied when the fault happened in sequence in all the sections with the i-combination of DG.

Reliability Improvement Index (RII) is illustrated as combination of these parameters as follows:

$$\left\{ \begin{aligned} & K_1 \times (\frac{AENS_T - AENS_i}{AENS_T}) + \\ & K_1 \times (\frac{SAIDI_T - SAIDI_i}{SAIDI_T}) + K_1 \times (\frac{CAIDI_T - CAIDI_i}{CAIDI_T}) \end{aligned} \right\} \quad (18)$$

where

Ki is coefficient factors and are considered 0.333 for each.

Multi Objective Based Problem Formulation: The multi objective index for the performance calculation of distribution systems for DG size and location planning with load models considers all previous mentioned indices by giving a weight to each index. The PSO-based multi objective function (MOF) is given by

$$MOF = \omega_1 * SSF + \omega_2 * PLRI + \omega_3 * RII \tag{19}$$

where

$$\sum_{i=1}^{3} \omega_1 = 1 \tag{20}$$

These weights are indicated to give the corresponding importance to each impact indices for the penetration of DG with load models and depend on the required analysis (e.g., planning, operation, etc.). The weighted normalized indices used as the components of the objective function are due to the fact that the indices get their weights by translating their impacts in terms of cost. It is desirable if the total cost is decreased. In this work, due to more important the stability factor respect to short circuit level, these weights are assigned as $w_1 = w_2 = w_3 = 0.3333$. However, these values may vary according to engineer's concerns, Subjected to various operational constraints to satisfy the electrical requirements for distribution network. These constraints are the following.

PSO-Based Optimization Method: In order to better clarify, the solution of optimization problem in regional level with PSO can be presented by an algorithm in five steps as follows:

Step 1: Initialization γ: In this step d, n, T, itermax, w, c1, c2 and velocities are assigned.

In this step, the lower and higher bound of regional constraints is specified too. Based above d initial particles are generated in random in the range of regional constraint. Set iteration=1.

Step 2: Objective Function Calculation: In this step the objective function and fitness value of each particle qi,d is calculated.

Compare fitness value of each particle with its qbest. The best fitness value among qbest is denoted as sbest.

Step 3: Velocity Modification: In this step the velocity of each particle is modified based on bellow equation and then generate the new particles based follow equation:

$$v_{dn}^{t\ r+1} = w.v_{dk}^{r} + c_1 * rand() * (qbest_{dk} - q_{dn}^{t\ (r)}) + c_2 * Rand() * (sbest_d - x_{dk}^{r}) \tag{21}$$

$$q_{dn}^{t\ (r+1)} = q_{dn}^{t\ (r)} + v_{dn}^{t\ (r+1)} \tag{22}$$

In these equations $q_{dn}^{t\ (r)}$ is a part of abobe equation in the rth iteration. It should be noted that $q_{dn}^{t\ (r)}$ is defined earlier, if v_{dn}^{t} reaches to its boundary values, it will be adjust to the extreme values. In other words, If $v_{dn}^{t} > V^{\max}$ then $v_{dn}^{t} = V^{\max}$. Similarly, If $v_{dn}^{t} < V^{\min}$ then $v_{dn}^{t} = V^{\min}$. Finally the all of regional constraints are checked and the offender particles are penalized with the penalty factor expressed by above equation:

Step 4: Upgrading of Qbest, Sbest: If the fitness value of each particle is better than the previous qbest, then qbest is updated with the current value. If the best qbest is better than sbest, then sbest will be substituted with the best qbest. This is the end of iteration. Set iteration=iteration+1.

If iteration>itermax then the algorithm is stopped unless it is continued by going to step 2. Otherwise step 5.

Step 5: Results of PSO: The particle that generates the latest sbest is the optimal solution of PSO.

Parameters used for the PSO with binary representation include in Table 1.

Table 1: Parameters of PSO

Indices	Parameter value
Num. of particles(d)	500
C1,C2	5
Wmax,Wmin	9,5
No. of iteration	500
$V_{qd}^{\min} V_{qd}^{\max}$,	$-0.5q_d\ 6q_d^{\max}$

1 to P for location and Cmin and Cmax for capacity, that R is the number of possible buses where DGs may be placed and Cmin to Cmax, that Cmin and Cmax are minimum and maximum possible capacity of DGs. So, a single solution can be defined as a specific allocation of individual DGs and protective devices on the feeder, i.e., the kth solution in the population is an (2N)-dimensional row vector of discrete numbers:

$$X_k = \begin{Bmatrix} [x\ y\ z] \mid x_i \in \{1,...,P\}, i = 1,...,N, y_i \in \{C_{\min},...,C_{\max}\} \\ z_j \in \{1,...,R\}, j = 1,...,M \end{Bmatrix}$$

where:

$$m \le M_{\max}$$

$$n \le N_{\max}$$

$$P_{\min} \le P_{DG}(i) \le P_{\max}$$

$$Q_{\min} \le Q_{DG}(i) \le Q_{\max}$$

$$\sum_{i=1}^{m} P_{DG}(i) \le P_{DG,total}$$

where:

The first part of constraint is related to DGs that is formed of number, possible location, active and reactive power for each source. The second part is related to permissible voltage of each load point in islanding mode and the last part is the number and possible location of MGs, so:

$$P_{DG-i,\min} \le P_{DG-i} \le P_{DG-i,\max}$$

$$Q_{DG-i,\min} \le Q_{DG-i} \le Q_{DG-i,\max}$$

$$V_{i-\min} \le V_i \le V_{i-\max}$$

In this paper DGs have capability of voltage control and they are modeled as constant power source in power flow study. The Newton-Raphson method is applied in each island and if one of the constraints about DGs or load point voltage has been broken the island will be shut down. For each combination of switches and DGs, reliability areas are determined. Then, considering the islanding capability of the network, reliability index is calculated after the fault simulation on each line. In order to calculate the loss and voltage profile and short circuit level, a complete power flow is applied. Finally, for each chromosome, the amount of objective function considering reliability index is calculated. In order to guaranty the reliability of system, the paper calculates the power not supplied after the three phases short-circuit.so the best location of DGs that lead to minimum energy not supplied are selected.

RESULTS

The proposed methodology is tested on test systems to show that it can be implemented in distribution systems of various configuration and size. The test system is a 12 bus system with and base voltage 20KV. The power factor (P.F) for each load point is 0.8. A single line diagram of the test system is shown in Figure 2.

The reliability parameters of distribution system are listed as Table 2.

The load point data of test system is listed in Table 3.

A computer program has been written in MATLAB 7.6 to calculate the optimum location and sizes of DG at various buses using PSO and reparative load flow method to identify the best location and size of DG. A complex Newton based load flow program is used to solve the load flow problem. The multi objective function optimally minimized is shown in Figure 3.

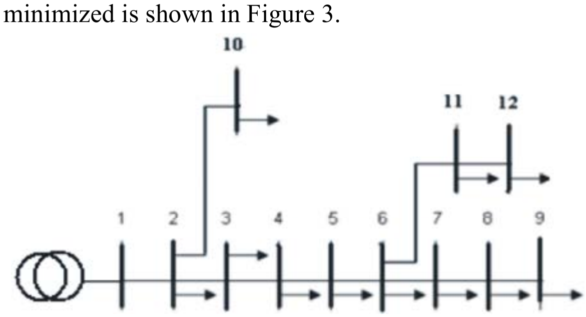

Fig. 2: Test distribution system

Table 2: Reliability parameters of distribution system

Feeders	Annual Failure Rate (λ_i)	Outage Time (Hour)
L1-2	0.20	2.0
L2-3	0.10	1.0
L2-10	0.15	0.5
L3-4	0.10	1.0
L4-5	0.10	1.0
L5-6	0.10	1.0
L6-7	0.10	1.0
L6-11	0.15	0.5
L11-12	0.15	0.5
L7-8	0.10	1.0
L8-9	0.10	1.0

Table 3: Load and customers at respective load point

Load	Load (MW)	No. of Customers
2	2.0	50
3	2.5	70
4	2.0	100
5	4.5	80
6	2.0	30
7	2.5	70
8	3.5	100
9	3.0	50
10	4.5	60
11	4.0	70
12	3.0	30

Table 4: Optimal DG unit sizes for 12-bus radial distribution system

Test System	Optimal Locations	Optimum DG Size in KW
12 bus	3	340.14
	5	350.38
	8	420.10
	10	510.20

Table 5: Results of power loss and average energy not supplied

Power Loss		AENS	
Without DG	With DG	Without DG	With DG
280.8 KW	218.5		35.20
	245.4	75.7 kwh/yr	45.40
	230.0		58.20
	240.8		64.20

By using the method described here, the best location in 12 bus system is in the order 3, 5, 8 and 10 and corresponding optimal sizes are 340.14 KW, 350.38 KW, 420.10 KW and 510.20 KW for reducing voltage deviation. This is listed in Table 4.

Results show that installing DG on system improve reliability indices and decrease power loss in system. Table 5 gives the total power loss in system before and after installing DG in optimal place with optimum result value. Also another index i.e. reliability index, show that average energy not supplied in system reduces when DGs are implemented in system at optimal locations.

By using the method described here, the best location in 12 bus system is in the order 3, 5, 8 and 10 and corresponding power loss are 218.5 KW, 245.4 KW, 230.0 KW and 240.8 KW, also corresponding average energy not supplied are 35.20 kwh/yr ,45.40 kwh/yr,58.20 kwh/yr and 64.20 kwh/yr.

Top ranked buses and their corresponding SSF and ISC with optimal DG size for 12 bus are shown in Figure 4

Figure 5 gives voltage profile of each bus in 12 bus radial system. The result shows the voltage level before and after installing DG.

Before DG installation, voltage level from bus number 6-12 is lower than 0.92 p.u. After DG installation, the voltage levels of these buses are improved with minimum of 0.96 p.u. for bus number 8. Further more if multiple DGs are installed, voltage level will be higher than the previous levels.

As shown in Fig. 5 the improvement in voltage profile under different load models. As shown in figure the voltage at all buses before inserting DG units to the system is higher than 0.90 pu except at buses 10, 11 and 12 in the case of constant load model. Due to the insertion of DG units, the voltage profile significantly improved for all studied load models. Improvement in voltage stability was observed from Fig. 6. in this figure the voltage stability index at each buses of system is shown.

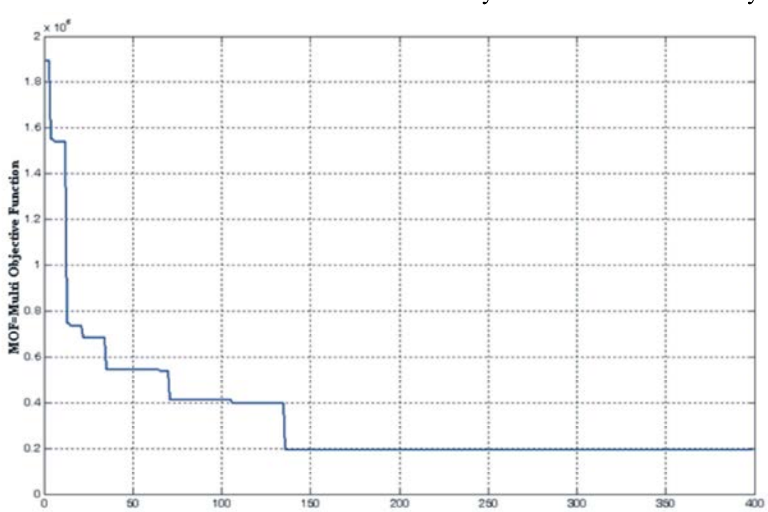

Fig. 3: Multiobjective function optimally minimized value versus iteration number

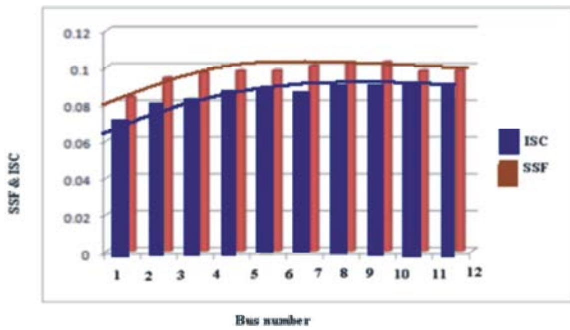

Fig. 4: SSF and ISC of each bus of system after installing DGs

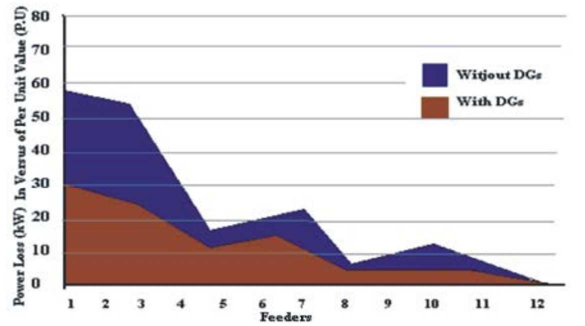

Fig. 7: Total active power losses for base case and DG installed

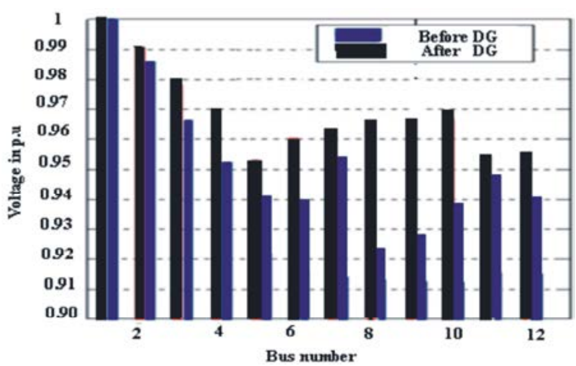

Fig. 5: Voltage profile before and after DG injection having optimum value

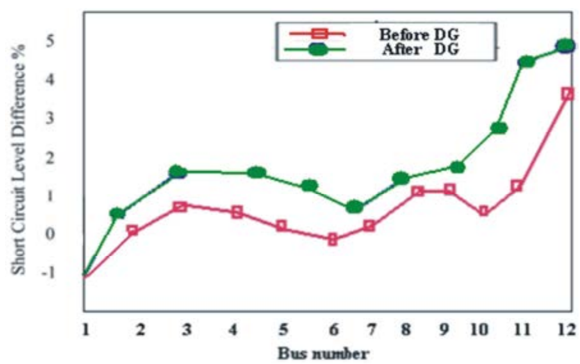

Fig. 8: The short circuit level difference of the system at each bus

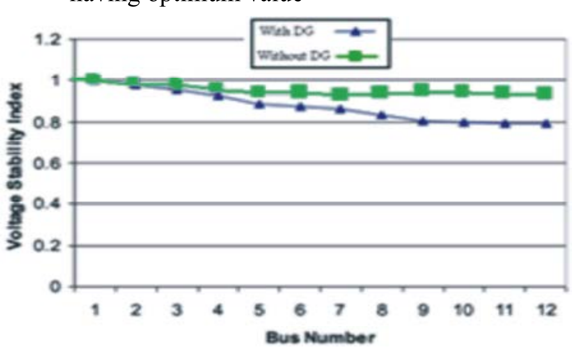

Fig. 6: Voltage Stability Index before and after DG installation at each bus of system

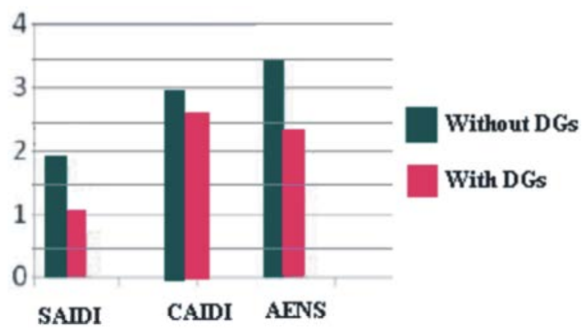

Fig. 9: Reliability indices before and after DG injection having optimum value

The power loss of system in presence of DG units is shown in Figure 7. As shown in this figure the power loss of system with DG is decreased compared the state that DG units are not in system.

Using optimum placement of distributed generation, the short circuit level at most of the system buses was increased. In Figure 8 the difference between the short circuit level at each bus of the system with and without DG as a percent of the value of short circuit level before placement of DG units in the system is presented. As it is indicated in figure, the maximum increase is very low where a maxi-mum difference of 3.92% occurred at bus 4.

The impact of DG units on reliability indices of system in terms of average energy not supplied, customers' average interruption duration index and system average interruption duration index is indicated in Figure 9.

CONCLUSION

In this paper the optimum placement of distributed generation with, multi objective function is considered and investigated. In this paper an objective function including four main goals is analyzed. Power loss reduction, voltage profile improvement, short circuit level improvement in order to increasing stability of distribution system with considering reliability indices have been investigated. The reliability index that considered in this paper is combination of customers average interruption duration index (CAIDI), system average interruption duration index (SAIDI) and total average energy not supplied (AENS). After optimizations of objective function with aim of power loss reduction, voltage improvement and stability increscent and obtain results, the reliability index based on AENS, SAIDI and CAIDI, is analyzed and best locations are selected. By using the method described here, the best location in 12 bus system is in the order 3, 5, 8 and 10 and corresponding optimal sizes are 340.14 KW, 350.38 KW, 420.10 KW and 510.20 KW for reducing voltage deviation . By using the method described here, the best location in 12 bus system is in the order 3, 5, 8 and 10 and corresponding power loss are 218.5 KW, 245.4 KW, 230.0 KW and 240.8 KW, also corresponding average energy not supplied are 35.20 kwh/yr, 45.40 kwh/yr, 58.20 kwh/yr and 64.20 kwh/yr.

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